Transmitting Tubes—How to Use and Abuse Them; Part I

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Some of the finer points of transmitter design are covered in this article by W6SAI. A lot of the information herein was gained "the hard way" covering 25 years' experience in designing and building transmitting equipment. Other data has been compiled from the many questions on these topics that have arisen in his work with a leading transmitting tube manufacturer. This is "must" reading for all owners of transmitters!

THE story has been told at hamfests that the data sheet enclosed in a vacuum tube box was included with the intention that it should be thrown away with the box and packing material. Contrary to this little story, the data sheet has been placed therein with good reason; to inform the user of the tube of the capabilities and limitations of the tube. The data sheet is a summation of the functions of the tube and covers the electrical and mechanical characteristics, the maximum ratings, and the typical operating conditions.

The rugged individualist usually ignores the data sheet and runs his tube at a temperature just below that at which the plate will start to melt. This may be fun, and may even evoke "oh's" and "ah's" from the visiting hams, but it violates the old "watts-per-dollar" evaluation of the vacuum tube!

After all, let's face it; there is an economic point beyond which it is impractical on a "watts-per-dollar" basis to push a tube. In general, the harder the tube is pushed, the shorter will be its life. This is analogous to the story of the cowboy who wandered into a western saloon and saw an old, grizzled prospector at the bar, drinking whiskey neat from a bottle, and smoking a huge, black cigar taken from a box of stogies at his elbow. Striking up a conversation, the cowboy learned the old gent drank three quarts of booze a day and smoked five boxes of cigars a day, too. Said he, "You are amazing! All this hard living at your age! You look like you must be ninety years old!" *"Ninety!"* screeched the prospector slamming his drink on the bar and reaching for his gun, "I'm only twenty two!"

So it is with the vacuum tube. Moderation is the secret to a happy, long tube life. The tube manufacturer sets maximum ratings on a basis of expected tube life. Each rating has been determined as the maximum value which will permit a reasonable life expectancy for the tube. The enemy of unlimited tube life is *heat*, but unfortunately heat is a natural consequence of making the tube work. A compromise of some kind must thus be made, and this is the purpose of the data sheet. Let's look into the compromise and see what establishes the various ratings given for transmitting tubes.

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Plate Dissipation

The plate dissipation (rated in watts) of all radiation (air) cooled tubes is limited by the maximum safe temperature of the plate, and the effects of this temperature on parts of the tube other than the plate. In general, plates of radiation-cooled tubes will withstand several times their maximum rated plate dissipation *for a short period of time*. Other parts of the tube, however, are affected greatly by excessive heat radiated by the plate. High levels of plate temperature cause the grid, filament, and glass envelope to become overheated, while the heat conducted away from the plate by the plate lead contributes to the heating of the plate seal.

These effects are not instantaneous, and short overloads do not usually overheat the adjoining tube structure to a damaging extent. However, the user has no way of telling to what degree he can safely exceed the plate dissipation, or over what length of time this abuse can take place. The maximum plate dissipation rating is intended to set a point at which continuous operation may be carried out without damage to any part of the tube, even though the other tube elements may at the same time be operating at their maximum ratings.

Regardless of other conditions, the maximum plate dissipation should not be exceeded in continuous operation.

Maximum Plate Voltage

Voltage limitations are set at a point above which the internal insulators of the tube may arc over, or above which the glass envelope will become damaged from dielectric losses. In addition, a plate voltage ceiling tends to set a limit to the r.f. charging current flowing in the plate and filament leads. The charging current is a function of the r.f. plate voltage, which in turn is a function of the d.c. plate voltage; this makes it possible to set a limit on r.f. charging current without the difficult task of determining the current directly.

Tube envelopes having grid and plate leads in close proximity are subject to a greater degree of glass stress than those having widely separated electrode terminations. In general, however, most glass tubes have maximum plate voltage ratings that fall in the r.f. charging current limit category.

Minimum Plate Voltage

Each tube has a particular plate voltage below which it is uneconomical to operate the tube. That is to say, the filament power consumed by the tube (and the initial cost of the tube) are so high that the cost of power developed by the tube is high in comparison to the same power generated by a cheaper tube. Of course, if the tube is purchased "surplus" at low cost, the economic picture changes so that the initial cost is of secondary importance. Even so, tube efficiency tends to drop when extremely low values of plate voltage are employed. In addition, multi-element tubes, such as the tetrode (the 813 or 4-250A, for example) have a definite *minimum* plate potential below which it is not wise to operate the tube. As the plate potential is lowered, the average screen current tends to rise and the screen dissipation increases accordingly. It can be possible to thereby damage a tube by excessive screen dissipation by operating it at a low plate potential.

Lowering the screen voltage to decrease the screen dissipation is but a makeshift cure, as the power gain and efficiency of the tetrode tube drops sharply as the screen voltage is lowered beyond the normal operating range.

Maximum Plate Current

Maximum plate current is based upon the available supply of electrons emitted by the filament of the tube. Filament emission is therefore the controlling factor determining maximum allowable plate current. The maximum figure is intended to set a value which may be easily realized throughout the life of the tube. If operating conditions are chosen which require the maximum plate current limitation to be exceeded at the start of tube life, it may become increasingly difficult to maintain the desired plate current as the tube ages. To have ample filament reserve, it is important to make sure that filament voltage is "up to snuff" at all times.

Filament Voltage

Proper filament voltage and the allowable departures therefrom are usually specified in the tube data sheet. In general, quick-heating thoriated tungsten filaments used in the larger power tubes may be operated over a range of plus or minus 5 per cent of the recommended voltage. Slower heating cathode type filaments used in small power tubes and external anode types usually have a filament operating range of plus or minus 10 per cent of the recommended voltage. Some variation in power output must be expected as the filament voltage is varied in this range. Lower than normal filament voltage will impair the power output of the tube, and higher than normal voltage will cause critical parts of the tube to run at an excessive temperature, and may even cause damage to the grid structure in extreme cases. In passing, it should be noted that an inexpensive a.c. type meter of plus or minus 5% accuracy can tell the operator little about filament voltage, when the voltage must be held to the same value of accuracy. Use a *good* filament voltmeter of known accuracy.

Maximum Grid and Screen Ratings

Element dissipation sets the grid and screen power limits. Excessive dissipation can result in electron emission from the element (termed primary emission), or can cause deformation or melting of the structure through overheating. In addition, the grid and screen structures can be overheated by excessive radiation from the plate.

A common type of screen damage results when the tube is operated with full screen voltage and low or nonexistent plate voltage. The screen then tends to act like the plate, and excessive screen current quickly boosts the screen dissipation to the point where the structure is permanently damaged. Thus, the tetrode should be protected against loss of plate voltage. Either the screen and plate voltage should be taken from a common supply, or some form of overload relay or safety device should be used that will break the screen voltage lead when the screen current exceeds a predetermined value.

Bulb Temperature

The glass envelope and lead seals of a transmitting tube must be maintained below a temperature at which the glass will soften, or the seals "leak" air. Tubes and components tend to become smaller year by year, but nobody has yet been able to miniaturize the watt, and assemblies run hotter as they are reduced in size. Also the tube's glass envelope will act as a conductor when it is too hot. Adequate ventilation is very important if maximum tube life is to be achieved. Heat is the great enemy of the vacuum tube and pains should be taken to conduct the heat away from the tube as efficiently as possible.

The most popular tubes used in amateur service are air cooled. The smaller tubes (and the larger old ones having long element support stems) may be cooled by *convection*, the heat rising from the envelope creating sufficient air movement to ensure that excessive element and seal temperatures are not reached. Compact, higher power tubes that have to dissipate large quantities of heat in a small area must have assistance in the form of air blown across the envelope, seals, and pins by an auxiliary fan or blower.

Short, squat tubes may require more cooling than long, thin tubes as the lead seals of the "shorties" are nearer the elements and are thus exposed to higher temperatures.

For most tubes the flow of cooling air is upward, consistent with the normal flow of convection currents. Large transmitting tubes have an open base structure and a matching socket which permits cooling air to enter the base end of the tube. The grid circuit area under the chassis, therefore, may be pressurized and the air introduced into this chamber by means of an external blower. The plate circuit area may have a mesh cover which permits the air to vent out readily, yet which provides a degree of circuit shielding. No holes in the chassis should be provided for the air to pass from the lower to the upper compartment other than by passage through the socket and tube base.

Do not sub-mount a tube with a metal base shell so that the chassis comes above the vent holes of the base. *Do not* mount above the chassis a tube with a metal base shell or the proper circulation of air will be impaired.

In the case of the external anode-style tubes (4X150A, for example) complete air system sockets are available that permit air to be blown axially on the base of the tube, past the base to the envelope, and then over the plate cooler. Use of other than such a special socket is "bad medicine" for the external anode tube, as the tube temperatures cannot be adequately controlled.

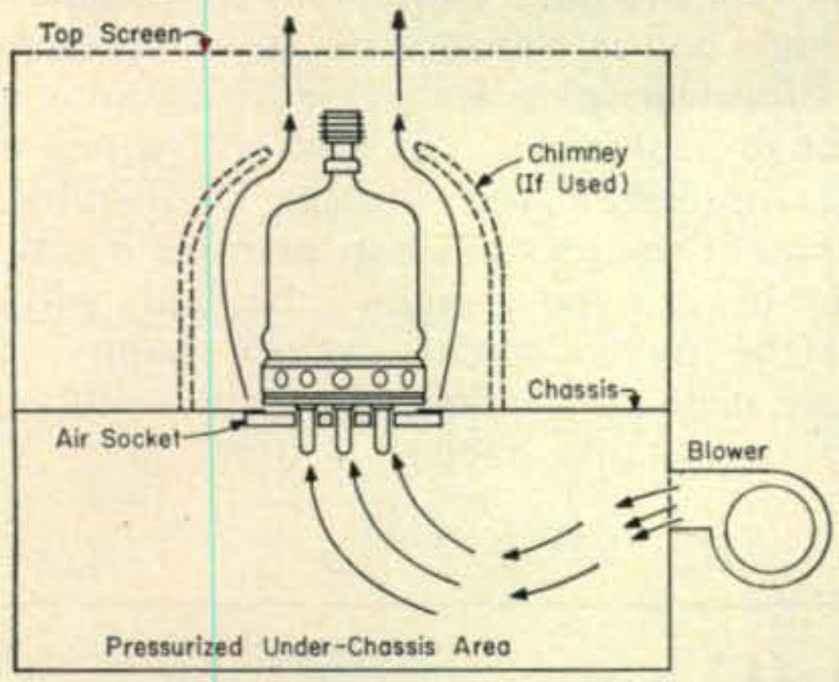

Fig. 1—Correct mounting of transmitting tube provides cooling, shielding, and isolation of input and output compartments. Cool air enters through grid circuit compartment below sockets, through a screened opening, passes through socket cooling the base end of the tube, sweeps upward cooling the glass envelope and into the output circuit compartment. The compartment has mesh-covered openings in top which permit heated air to vent out readily. This arrangement applies whether the tube is cooled by forced air or by convection circulated air.

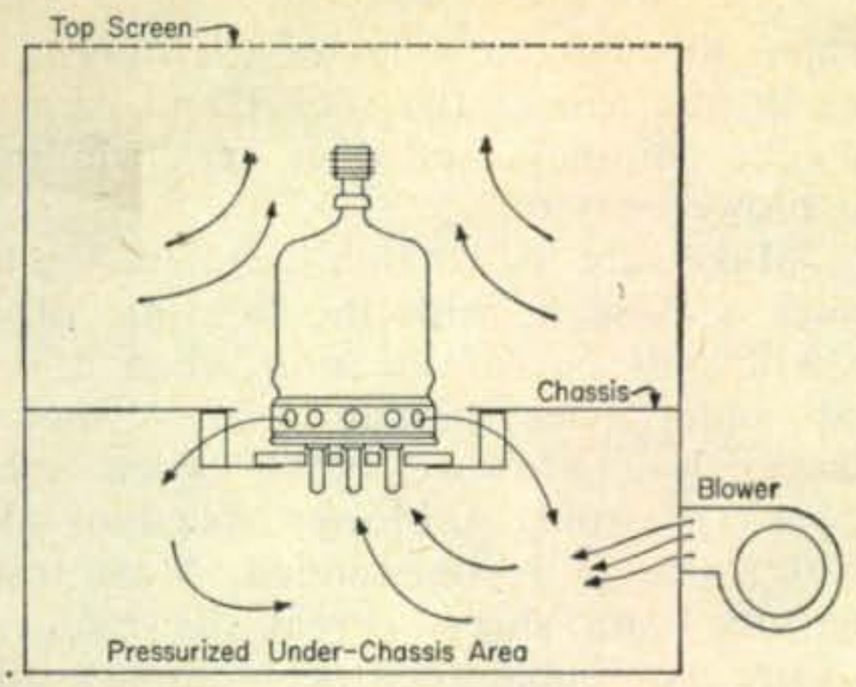

Fig. 2—Do not sub-mount a tube with a metal base shell so that the chassis deck comes up above the vent holes of the base shell of the tube. No improvement in isolating input and output circuits results, and such an arrangement prevents the flow of cooling air about the envelope and seals of the tube. If a tube must be recessed into the chassis because of space limitations, a recessing cylinder with wide clearances should be used to permit the air from the base holes to vent properly into the compartment above the chassis.

Use of a receiving type loctal socket with external anode tubes is not recommended, as dangerously high stem temperatures will be generated from the heat of the filament unless the base structure is cooled by an air blast, and the solid construction of the loctal socket blocks the normal flow of air above the tube stem.

Construction Techniques for Forced-Air Cooled Tubes

In general, the under chassis area should be made air tight, and a suitable fan or blower used to pressurize the compartment. The intake air vent should have a large area to provide a minimum resistance to the flow of air. Air holes may be screened as a TVI-preventive measure, but such impediment reduces the passage of the air by a large degree.

As it is difficult to measure the air flow to a tube, and even more difficult to measure the envelope and seal temperatures of the tube, the following "rules of thumb" may be observed in order to achieve optimum cooling and longest tube life.

1—Use the maximum amount of forced air possible. It is wise to employ a blower delivering at least twice the recommended volume of air. Turn the air blast on at the same time the filament is turned on, and leave it on as long as the filament is lit.

2—Inexpensive squirrel-cage blowers often do not work properly when delivering air into a back pressure "load" created by the socket, tube and chimney. A large quantity of air

escapes through the sides of the blower. Make sure the air *enters* the socket and *escapes* via the tube chimney, and does not "windmill" in the blower cavity.

Make sure the rotatable cage of the blower makes a close fit with the housing; otherwise air will spill out of the unit when it is operated under back pressure. Most low speed blowers lose pressure badly when subjected to back pressure. A blower speed of at least 3,100 r.p.m. is recommended. Most transmitting tube data sheets reveal the required air pressure (in cubic feet per minute) and the back pressure (in inches of water) that must be developed as pressure-drop across the socket. Most blower manufacturers provide data sheets which show the blower output (in cubic feet per minute) that the unit develops for various values of back pressure (in inches of water, or static pressure). You can be reasonably sure your tube is adequately cooled if you choose a blower that develops about *twice* the required number of cubic feet you need at a specified back pressure. Beware of midget and surplus unmarked blowers, or blowers with loose fitting housings!

3—Make sure the cooling air reaches the socket and make sure the exhaust air leaves the vicinity of the tube. It does no good to pump cooling air to a tube and then have no path for the warmed air to escape.

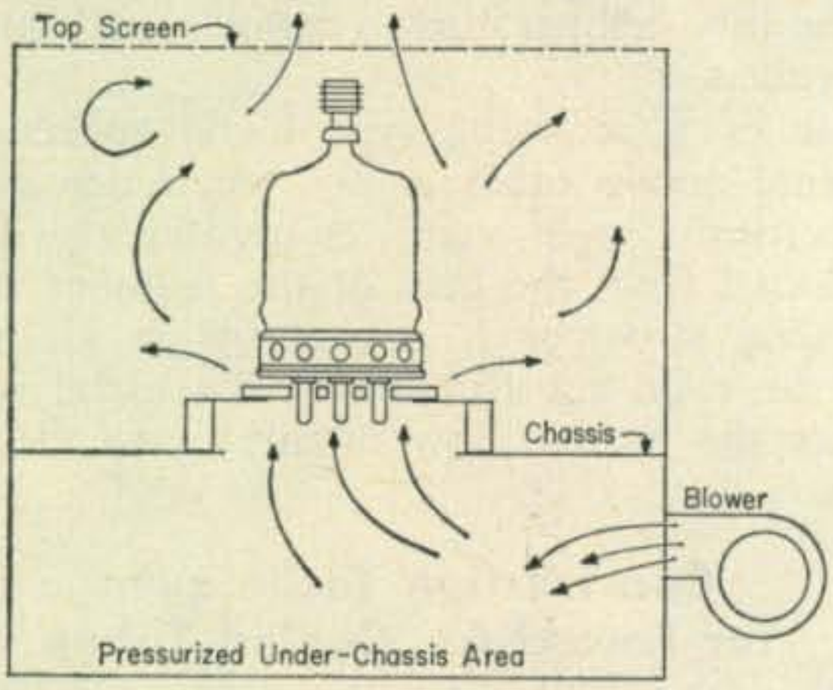

Fig. 3—Do not mount a tube with a metal base shell above the chassis unless the area between the socket and the chassis is sealed to prevent air from escaping from beneath the tube base. Circuit isolation is not improved by this form of mounting, and proper cooling is impaired. If the tube must be raised above the chassis for some reason, it should be mounted on the top surface of an air-tight cylinder that funnels the air up into the socket cooling holes.

4—A large amount of heat escapes from glass tubes by radiation of energy from the tube plate. Placing the tube near polished metal surfaces that reflect radiant energy back to the elements of the tube is a sure way to raise the internal temperature of the tube. It is a good idea to space the tube away from such surfaces by at least the diameter of the tube envelope.

No simple rules can be given to accommodate all tube installations in all possible equipments. Tubes can be damaged by lack of air, but never by too much air, unless the blast is strong enough to lift the tube out of the socket and smash it against your ceiling! Use the largest blower you can afford. A great deal can be learned about air flow by puffing cigarette smoke into the blower and observing the path it takes in quitting the amplifier.

Connections to the Tube

Connections to the plate cap of transmitting tubes should be made with a section of flexible strap or braid to prevent any lateral strain from being placed on the tube electrode. Those tubes having a rod-type plate lead (such as the 304-TL) are prone to damage if the plate connector is forced on the rod until the former touches the glass envelope. Under heat, the expansion rate of the glass, the plate rod, and the connector are all different, and it is possible for the connector to press against the envelope and cause a fracture of the glass.

There Is Hope!

Don't let all this gloom and doom discourage you from building equipment and using modern high power transmitting tubes! It is merely that "forewarned is forearmed." By anticipating minor difficulties such as outlined in this article and eliminating the sources of trouble, the equipment in question can provide a long and happy life for the vacuum tube. This will make you (the owner and operator) happy, and—believe it or not!—make the vacuum tube manufacturer equally happy!

[*To be continued*]

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Transmitting Tubes—How To Use and Abuse Them; Part II

BY WILLIAM I. ORR*, W6SAI

Part I of this series dealt with some of the problems encountered with transmitting tubes that were a direct result of the operating temperature of the tube. This second, and concluding part covers circuit design, parasitic suppression and component parts.

THE schematic of a transmitter or amplifier rarely provides the constructor with sufficient information concerning circuit layout or choice of proper components. In many instances, the designer must pick up this information by experience. This is often the costly way, as a design error or poor component choice can often lead to costly equipment failure or to tube damage!

The whole problem of circuit design, parasitic suppression, and choice of components can be summed up in one thought: *maintain isolation between output and input circuits.* This idea is easy to express, but not so easy to accomplish!

All component parts of the grid or input circuit (and earlier stages) must be isolated from the plate circuit compartment. Similarly, plate circuit components must be kept out of the input compartment. If this situation is achieved, a condition of maximum circuit stability will result.

Unhappily, tubes and circuit components are not perfect. They are finite in size, and thus are a fraction of the wavelength at which they operate. Capacitors have residual inductance, and tube lead inductance enters the picture. The problem of component size can be partially solved by making tubes and parts smaller. However, until some genius miniaturizes the watt, the problem of radiating heat in smaller and smaller spaces becomes formidable. As a result, it becomes impractical to reduce the size of tubes and components to the vanishing point.

Because of their physical size, bypass capacitors have a certain critical frequency above which their effectiveness is impaired. At the same time, the internal structure of vacuum tubes becomes large in relation to the wavelength as the frequency of operation is raised. As these two effects grow, the circuit efficiency is impaired, and the tube operation becomes less efficient. Proper circuit design will help to reduce these unwanted effects to an absolute minimum.

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The Common Screen Circuit

It must be noted that the screen lead of the tetrode or pentode tube (and connections to it via the socket) are common to both the input and output resonant circuits. Because of the plate-screen capacitance of the tube, the r.f. plate voltage developed in the output circuit causes an r.f. current to flow out the screen lead to the chassis (ground). In the case of a push-pull stage, this current may flow from the screen terminal of one tube to the screen terminal of the other tube. Similarly, due to the control grid-screen capacitance of the tube, the r.f. voltage in the input circuit will cause an r.f. current to flow in this same lead to the chassis, or to the opposite tube of the push-pull circuit.

The inductance of the screen lead is common to both the input and output circuits. This inductance, though small, is important, and its effect becomes more pronounced as the operating frequency of the tube is raised. At audio frequencies and low radio frequencies, the screen lead inductance may be safely ignored, as its effects are negligible. As the frequency of operation of the tube approaches the higher portion of the r.f. spectrum the lead inductance plays an increasingly larger part in the operation of the tube and the circuit. At some high critical frequency, the inductance can no longer be ignored, as it starts to affect the operation of the tube. In addition, the residual inductance of the tube socket and screen bypass capacitor enter into the picture as the frequency of circuit operation is raised.

The tetrode elements involved in feedback circuits are shown in fig. 1. These circuit elements are inherent and inside the vacuum enclosure of the tube and include the residual interelectrode capacitances, and the inductance of the screen lead. The r.f. voltage developed in the plate circuit (E_p) causes a current (I) to flow through the plate-screen capacitance and also through the inductance (L) in the screen lead. The passage of this current through (L) develops a voltage ($-E$) which has a polarity opposite to that of the r.f. plate voltage.

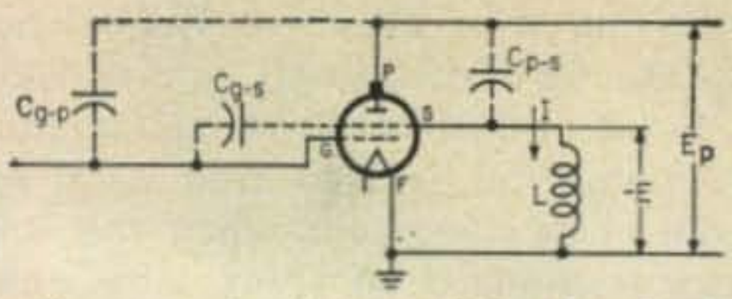

Fig. 1—The tetrode characteristics involved in parasitic feedback circuits include the interelectrode capacitances of the tube and the inductance of the screen to ground path *(L)*. The plate-screen capacitance, together with the inductance of the screen-ground path, develops a potential *(-E)* on the screen which is a portion of the r.f. plate potential. Screen inductance *(L)* is made up of internal inductance of the screen lead, plus inductance of socket and screen bypass capacitor.

Analysis of the Tetrode Neutralizing Circuit

These circuit elements have been arranged in fig. 2 with a graphical representation wherein the height above or below the zero line (X-axis) represents the magnitude and polarity of the r.f. voltage of that part of the circuit with respect to the filament r.f. potential (normally zero). Because all of the circuit components involved are pure reactances, the voltages are either in-phase or out-of-phase and so can be represented as positive or negative with respect to each other. Voltages plotted are the components of the r.f. output voltage (E_p) and grid driving voltage is not shown. The plate (P) is shown at a high positive potential. If the circuit is perfectly neutralized, the grid (G) lies on the zero potential line (filament potential) insofar as any action of the r.f. plate voltage (E_p) is concerned. *When no component of output voltage exists between grid and filament, the circuit is neutralized and a condition of maximum isolation exists.*

The voltage developed in the screen lead inductance (L) places the screen (S) at a negative r.f. potential ($-E$) with respect to ground. The total r.f. voltage between plate and screen comprises the plate voltage (E_p) plus

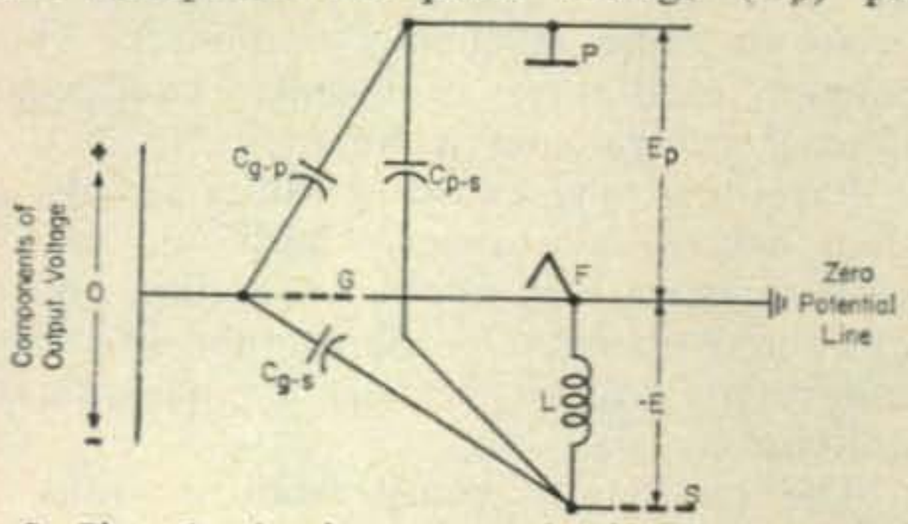

Fig. 2—The circuit elements and r.f. voltages of the tetrode may be arranged in graphical form, wherein the height above (or below) the X-axis represents the magnitude and polarity of the voltage of that part of the circuit with respect to the filament potential. In a grid-driven circuit, the filament is normally at ground potential. If no component of the output voltage is developed between grid and filament, the circuit is neutralized. Shown above is the representation of a tetrode tube at the self-neutralizing frequency.

the screen lead inductance voltage ($-E$). This total voltage is applied across a potential divider consisting of the grid-plate capacitance ($C_{g\text{-}p}$) in series with the grid-screen capacitance ($C_{g\text{-}s}$). When this potential divider is suitably matched to the magnitude of E_p and $-E$, the control grid will have no voltage difference to the filament and (by definition) the circuit is completely neutralized.

The Self-Neutralizing Effect

It should be noted in fig. 2 that the potential dividing action between the grid-plate and the grid-screen capacitances will not be affected by the operating frequency of the tube. On the contrary, the division of voltage between plate and screen, and screen and ground due to the screen charging current (I) flowing through screen lead inductance (L) will vary greatly with frequency. There will, therefore, be some particular frequency at which the potential dividing capacitance places the grid at filament potential as far as plate circuit parameters are concerned. This is called the *self-neutralizing frequency* of the tetrode. At this *one particular frequency*, the tetrode is inherently neutralized due to the circuit elements within the tube structure (and any external added screen lead inductance to ground). The self-neutralizing frequency varies from 25 mc (for large transmitting tubes of the 4-1000A class) to about 100 mc (for small tubes of the 6146 class). The self-neutralizing frequency of external anode tubes (4X150A, for example) is of the order of several hundred megacycles.

Neutralization Below the Self-Neutralizing Frequency

Standard neutralizing circuits suffice below the self-neutralizing frequency of the tetrode tube. Normally, the feedback within tetrodes is a very small fraction of the feedback present in triodes. For low frequency operation, the isolation provided by a tetrode is enough so that in many cases external neutralizing circuits are not necessary to counteract the small amount of feedback. Whether or not neutralization should be used in the higher frequency region of the spectrum depends entirely upon the tube type, the operating conditions, and the degree of isolation desired between input and output circuits. It must be remembered that modern high gain tetrodes can provide almost full output with negligible grid excitation. Unless suitable precautions are incorporated in the electrical and mechanical design of the amplifier, energy feedback (other than that through the tube) will inevitably occur. Suffice to say that unless the tube and stray feedback paths are neutralized a condition can exist that could lead to circuit instability.

Neutralization Above the Self-Neutralizing Frequency

The self-neutralization point offers a clue as to the proper steps to be taken to ensure that

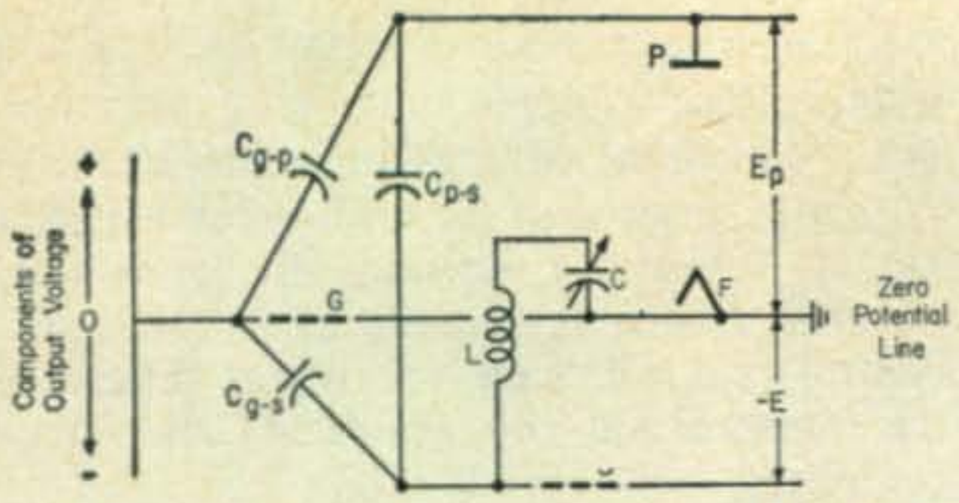

Fig. 3—This illustrates the components of the output voltage of a tetrode tube when the v.h.f. stage is neutralized by added series screen-lead capacitance. This neutralizing technique is frequency sensitive. Varying series capacitor, C, will adjust magnitude of E_p and $-E$ to the potential divider made up of grid-plate and grid-screen capacitances.

the tetrode circuit is properly designed for a high order of stability. When the tube is operated *below* the self-neutralizing frequency, normal neutralizing circuits will apply, as the effect of the screen inductance (L) is small. If the operating frequency is *higher* than the self-neutralizing frequency, the voltage ($-E$) developed in the screen grid lead inductance is too large to allow proper voltage division between the internal capacitances of the tube. Suitable circuit stability and neutralization may be accomplished by moving the self-neutralization frequency of the tube to the frequency of operation, thus reducing the voltage developed across the screen inductance to a negligible amount. One obvious method of reducing the voltage in the screen lead is to series tune the screen circuit to ground so as to lower the total reactance. This circuit may take the form of a variable capacitor placed between screen and ground, as shown in fig. 3. The capacitor is adjusted so as to provide minimum feed-through of energy between grid and plate circuits. This neutralization technique, however, is frequency sensitive and the capacitor must be adjusted if an appreciable change in operating frequency is made.

A second neutralization technique is to alter the potential divider network made up of the tube capacitances (fig. 4). This can be done by adding capacitance external to the tube between grid and plate. The value of this capacitance is roughly equal to that value normally used to neutralize the tube at lower frequencies, and can take the form of a small wire or rod standing up beside the tube "looking" at the plate. This configuration is also frequency sensitive and requires readjustment when the operating frequency is changed an appreciable amount.

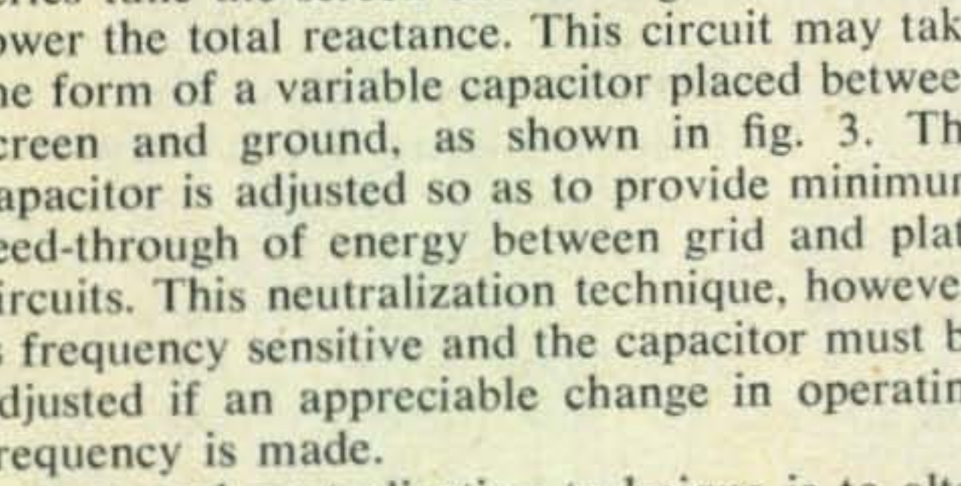

Fig. 4—This illustrates the components of the output voltage of a tetrode tube when the v.h.f. stage is neutralized by added external grid-plate capacitance (C_{ext}). This neutralizing technique is also frequency sensitive. The capacitance of the potential divider is adjusted, in this case, rather than the screen circuit impedance (L).

If a tetrode r.f. amplifier operating above its self-neutralizing frequency must tune over a range of frequencies, it is probably easier to use the series screen tuning technique and make the control available to the operator. This capacitor will be of the order of 50 or 100 mmf.

Another method of moving the self-neutralizing frequency of the tetrode to the operating frequency is shown in fig. 5. The screen is bypassed to the filament circuit of the tube, and inductance is introduced in the common filament and screen ground lead. In effect, the filament is tapped up the screen inductance to a point where the r.f. voltage difference between grid and filament is zero insofar as the components of the plate voltage are concerned. This configuration will be found to be self-neutralized at a higher frequency than if filament and screen terminals were separately bypassed to ground.

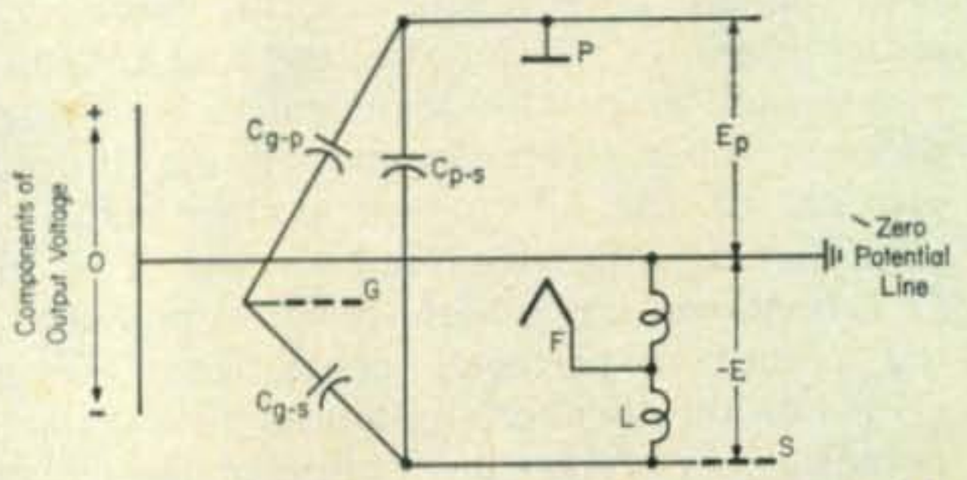

Fig. 5—The components of the output voltage of a tetrode tube may be neutralized by adding inductance to the common screen and cathode return. Grid and filament are maintained at same negative potential with respect to zero potential point.

Parasitic Oscillation

Parasitics are undesirable oscillations either of very high or very low frequency which may occur in radio frequency amplifiers. The unwanted oscillation is usually unaffected by normal neutralizing techniques.

Parasitics may cause spurious signals, other than normal harmonics, "hash" on each side of the carrier, key clicks, instability, and other unwanted phenomena. Short tube life, or tube failure may result because of parasitic oscillations.

The oscillations result from spurious series or parallel resonant circuits that exist as part of the normal tube connections. As most modern tubes exhibit considerable power gain well into the v.h.f. portion of the spectrum, it is very easy for the tube to oscillate at some random frequency determined by the parasitic resonant circuit. Insufficient circuit isolation will enhance the tendency of the tube to oscillate at the parasitic frequency.

Parasitic oscillation may take place at the operating frequency of the tube, at some lower

frequency determined by unwanted resonant circuits, or at some higher frequency at which the screen lead inductance of the tube has permitted a flow of energy between the grid and plate circuits. Elimination of low frequency and operating frequency parasitic oscillations can be accomplished by proper neutralizing techniques and avoidance of resonant circuits in r.f. chokes and auxiliary circuit wiring.

V.h.f. parasitics are a separate and distinct problem that often requires considerable circuit finesse and sophistication to conquer. In general, v.h.f. parasitic oscillations in tetrode transmitting tubes take place well above the frequency of self-neutralization, and neutralizing techniques designed to stabilize the circuit at the operating frequency often tend to make matters worse in the frequency region at which the parasitic oscillations take place. That is to say that low frequency neutralizing schemes often permit additional feedback of unwanted energy above the self-neutralization frequency! The problem can be solved in two ways: by increasing the self-neutralizing frequency of the tube and circuitry, or by lowering the frequency of the v.h.f. parasitic oscillation (increasing the inductance of the parasitic circuit). With proper techniques, the frequency of parasitic oscillation can be made to approach the self-neutralizing frequency of the tetrode and so suppress the parasitic. In addition, the v.h.f. parasitic circuit can often be loaded to such a degree that the tube gain at this frequency is not high enough to sustain oscillation.

The v.h.f. parasitic oscillation involves the interconnecting leads of the tube, the bypass capacitors, and the tuning capacitors. All of these elements possess residual inductance, and are a part of the v.h.f. circuit that permits oscillation (or instability). As shown in fig. 6, the v.h.f. parasitic circuit usually uses the capacitors of the fundamental tuned circuits as bypass capacitors, and the associated grid and plate leads for the inductances of the parasitic tuned circuit. For most tetrode transmitting tubes, the v.h.f. parasitic oscillation usually falls in the 90 to 170 mc region.

During parasitic oscillation, considerable r.f. voltage exists on the screen of the tetrode tube, and the screen bypass capacitor may be damaged by excessive voltage. It is wise, therefore, to employ a capacitor whose d.c. working voltage is equal to twice the maximum screen voltage. In addition, the screen capacitor must be rated to carry the r.f. current flowing between screen and ground. The capacitor should have low lead inductance and should be wired into the circuit with the shortest possible connections.

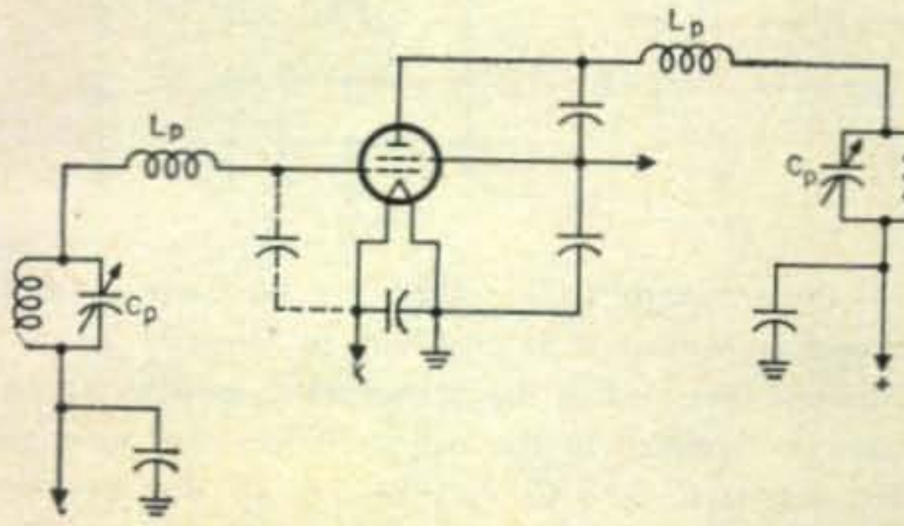

Fig. 6—Parasitic circuit of the tetrode amplifier uses lead inductance (L_p) and distributed capacitances for tuned circuits. Plate and grid tuning capacitors (C_p) usually serve as bypass capacitors at parasitic frequency. Parasitic oscillation may be eliminated by loading the spurious circuit, or by lowering parasitic frequency to the self-neutralizing frequency of the tube.

Parasitic Suppression

There are several practical methods of parasitic suppression, all of which involve varying the parasitic frequency of the circuit, or inserting "lossy" suppression devices at the parasitic frequency.

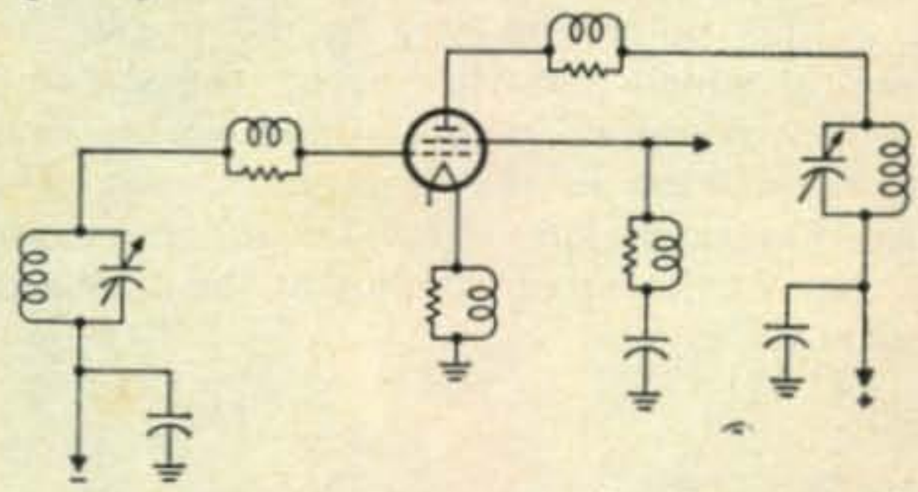

Fig. 7—Parasitic suppressors may be placed in plate, screen, grid, or filament paths. Suppressor must have sufficient wattage to dissipate that portion of fundamental power flowing through resistor. As voltage drop across suppressor increases with frequency, 10 and 6 meter operation places greatest load upon suppressor designed for v.h.f. parasitic circuit.

Plate Circuit Suppression—Shown in fig. 7 is an *R-L* type plate circuit parasitic suppressor. A small coil and resistor combination is placed in series with the plate lead between the tube and the tank circuit. The suppressor may be made up of a non-inductive resistor of 50 to 100 ohms, shunted by three or four turns of #12 wire, about ½-inch diameter and ½-inch long. In some cases it may be necessary to use such a suppressor in both grid and plate leads. The suppressor operates on the principle that

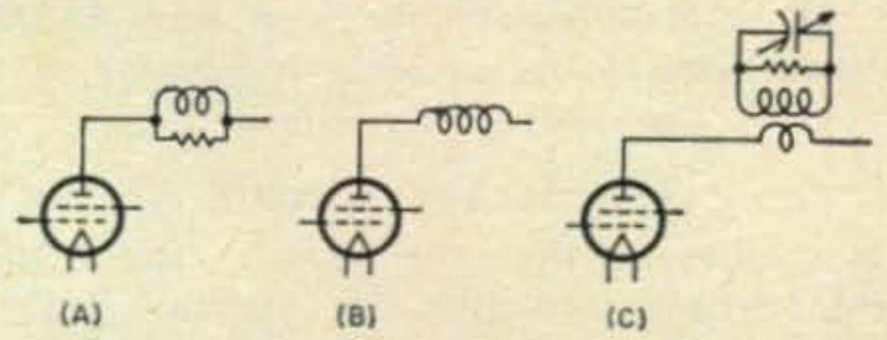

Fig. 8—Resistor-capacitor combination (A) in plate lead serves as efficient parasitic suppressor. The small r.f. choke (B) lowers parasitic frequency to the self-neutralizing region of tube. A parasitic suppressor may be tuned and coupled inductively to plate circuit for v.h.f. operation of a tube (C). The suppressor is tuned to the approximate parasitic frequency by a 30 mmf trimmer capacitor. The link coil in plate lead is two turns of the same size and configuration as parasitic coil. A high-power (kilowatt amplifier level) parasitic suppressor may make use of 43 ohm "Globar" 10 watt resistor (Workman, Inc., model RF-43) usually found as a TV replacement item.

the resistor is placed across an appreciable portion of the v.h.f. parasitic resonant circuit, but is shunted by the coil for the lower frequency fundamental signal.

Plate Circuit Choke—A simple form of v.h.f. choke can be placed in the plate lead, as shown in fig. 8. The size of the choke may vary considerably, depending upon the tube and circuit layout, and will run from four to ten turns of #12 wire, about ½-inch diameter. The presence of this choke in the frequency determining portion of the circuit lowers the frequency of the possible v.h.f. parasitic so that it falls near the self-resonant frequency of the tube and bypass leads.

Screen Circuit Suppression—As the screen of the tetrode is a portion of the parasitic circuit, it is possible to incorporate a suppression device at this point (fig. 9). At the higher frequency at which parasitics occur, the screen is no longer at ground potential and a suppressor may be inserted in the lead, as shown. This device has negligible effect on the bypassing efficiency of the screen circuit at the operating frequency.

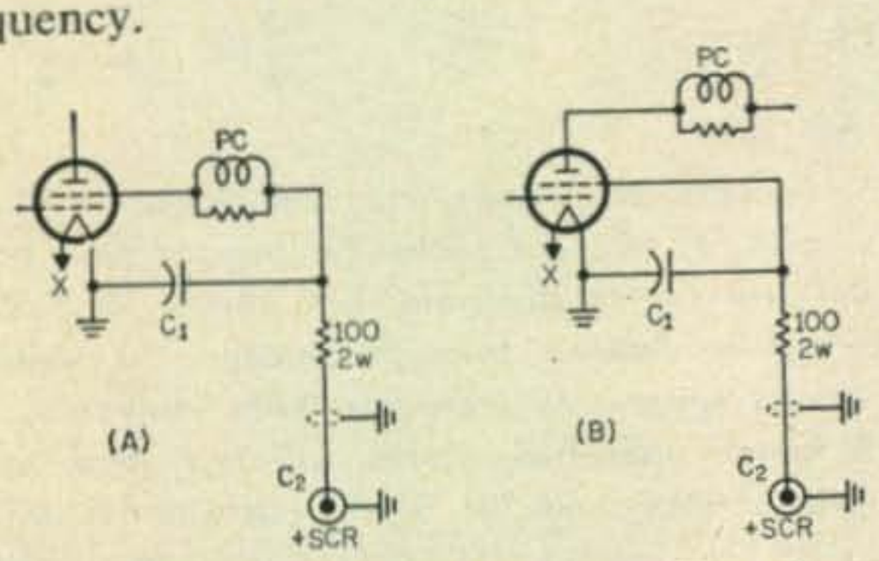

Fig. 9—Screen isolation of the tetrode tube is of prime importance. To decouple the screen from external influences, the screen lead should enter the amplifier chassis via a coaxial capacitor (C_2) such as the Sprague "Hypass" type. The screen lead within the amplifier is shielded, and is decoupled from the screen terminal by a 100 ohm, 2 watt composition resistor. The screen bypass capacitor (C_1) should have low internal inductance. One of the best types to use is the Centralab #858-1000. The parasitic suppressor may be placed in the screen lead (A), or in series with the plate lead (B). Note that the screen bypass capacitor is returned to one grounded filament lead.

The Screen Circuit

It is obvious that the screen circuit of a tetrode tube is sensitive to external voltages, and every attempt should be made to ensure that the screen remains as close to filament potential as is possible. In addition, precautions should be taken to prevent external sources of r.f. power from feeding energy *into* the screen circuit, thus introducing unwanted voltage into this element of the tube. It is necessary, therefore, to decouple the screen lead from the power supply circuitry as shown in fig. 9. Screen voltage is introduced to the amplifier via a coaxial type capacitor mounted on the chassis, and is fed to the tube socket by means of a length of shielded wire. The screen is

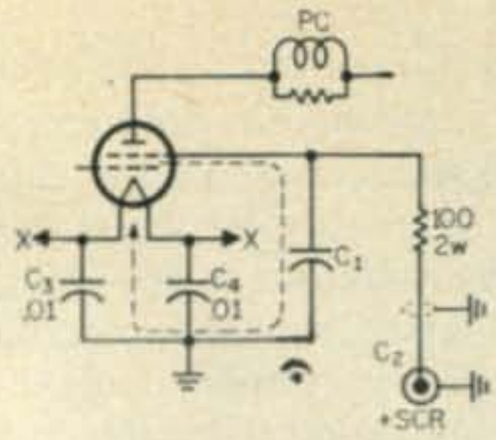

Fig. 10—Bypassing both filament leads to ground introduces the filament capacitors (C_3 and C_4) into the screen-filament circuit (dotted line). Inductance of filament capacitors is thus introduced into r.f. path between screen and filament, which enters into the neutralizing scheme shown in fig. 2.

further decoupled from the power source by means of a series resistor and shunt capacitor combination.

The screen-filament return should have as low an r.f. impedance as possible. Choice of screen bypass capacitor is important, as is the physical placement in the layout. Tubes having double screen terminals (the 4-250A family, for example) should have each screen terminal bypassed *to the adjacent filament terminal*. Disc-type, 1.2 kv ceramic capacitors may be employed, using the shortest possible leads. Placing the screen bypass capacitors to ground introduces the filament bypass capacitors into the screen-filament circuit, and should be done with caution.

If a low inductance bypass capacitor is available, it is possible to strap the socket screen terminals together and bypass the strap to ground via a parasitic suppressor as shown in fig. 9A. This technique works well to at least 30 mc, but has not been tried in the 50 mc region. The configuration of fig. 9B, however, has been found to work well in the 50 mc region for tubes whose self-neutralizing frequency lies above 50 mc.

The Filament Circuit

It is of utmost importance that the filament circuit of the grid-driven amplifier be maintained at ground potential. This is not as easy

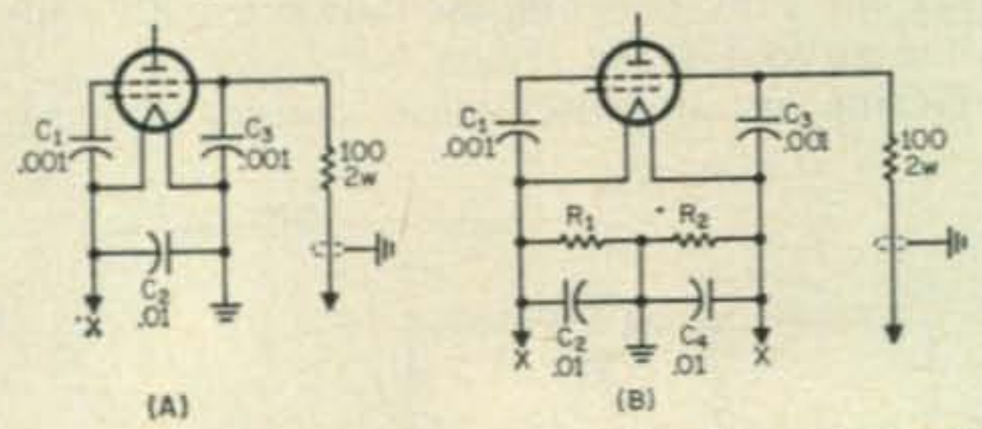

Fig. 11—In order to ensure that the filament remains at ground potential it is prudent to directly ground one filament terminal at the tube socket, and to bypass each screen terminal to the adjacent filament terminal (A). Capacitors C_1 and C_3 may be 1.2 KV disc ceramic units. High voltage units are required, not only to withstand the screen voltage, but to allow sufficient r.f. current carrying capacity, which is roughly proportional to the voltage rating of the capacitor. Each filament leg may be grounded by *R-C* combination (B) if balanced filament circuit is desired. Capacitors C_2 and C_4 may be 600 volt, .01 mf disc ceramic units.

to do as it sounds, as the filament leads within the tube have considerable inductance, and the filament bypass capacitors are not without residual inductance. In order to ensure that the filament is at ground potential it is prudent to directly ground one leg of the filament to the chassis at the tube socket (fig. 11). If it is desired to balance the filament circuit to ground, each filament leg may be bypassed to ground with a low inductance capacitor, shunted with a 10 ohm, 2 watt composition resistor. The resistor will "de-Q" the capacitor and the *R-C* combination presents a relatively low impedance path to ground well into the v.h.f. portion of the spectrum.

Wide Band Neutralization Technique

It is apparent that neutralization techniques must change as the operating frequency of the tetrode tube passes through the frequency of self-neutralization. It is possible to make a tetrode amplifier operate smoothly through this transition region by changing the neutralization system. In some equipments, this is automatically accomplished by the bandchange switch, as shown in fig. 12.

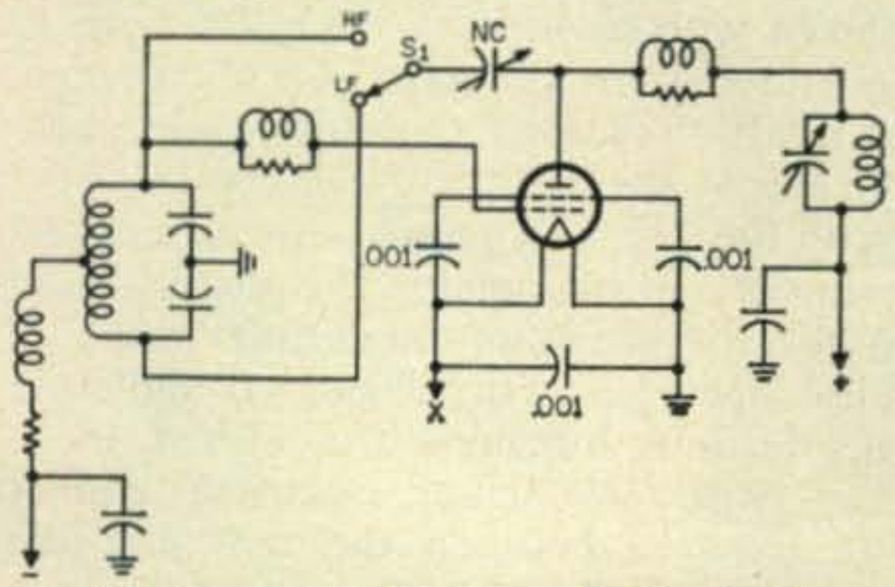

Fig. 12—Effective neutralization of tetrode tube operating on both sides of self-neutralizing frequency may be achieved by switching the neutralization circuit in conjunction with bandswitch position. Operation at the self-neutralizing frequency requires that external neutralization circuit be disconnected.

Checking for Parasitic Oscillations

Parasitics are most easily found in a stage by running it with a full plate and screen voltage, no excitation, and sufficient bias to limit the plate current to a safe value. The screen voltage should be applied through a protective series resistor which will limit the screen current to a safe value if and when the stage breaks into oscillation. A variable voltage transformer (Variac) on the primary of the high voltage (and screen) power supply is advantageous, and the supply should be fused.

The stage is coupled to a dummy load and tuned up in correct operating shape. Protective bias is applied at all times. If a variable voltage primary transformer is not at hand, a lamp bulb should be added in series with one leg of the primary circuit of the high voltage supply. As the plate current increases during a period of parasitic oscillation, the voltage drop across the lamp increases, and the effective plate and screen voltage drops. Bulbs of various sizes may be tried to adjust the voltage under testing conditions to the correct amount. Don't test for parasitics unless some means of voltage control is at hand. When a stage breaks into parasitic oscillation, the plate current increases violently and some protection for the tube under test must be used. Monitor both the plate voltage and the plate current, as well as the screen current.

The r.f. excitation to the stage is now removed. The grid, screen, and plate currents should drop to zero with cut-off bias applied to the tube. Grid and plate tuning capacitors are adjusted to minimum capacitance. No change in resting currents should be observed. If a parasitic is present, grid current will flow, and there will be an abrupt increase in plate current. The high voltage should be set so that oscillation maintains itself without exceeding the various dissipation ratings of the tube. Frequency of oscillation may be determined with an absorption wavemeter brought near the plate circuit of the stage. Suppression circuits may now be applied to the stage, and their effectiveness can be judged by the ease of parasitic oscillation, or the complete lack thereof.

When the stage is modified so that it can pass the above test, the protective bias is reduced until the tube dissipates the full plate rating when maximum plate voltage is applied, under condition of no grid excitation. Stage gain is extremely high, and it may be that the parasitic oscillation will show up once again. Further suppression measures must therefore be applied to the circuit.

It is common experience to develop an engineering model of a new item of equipment that is apparently free of parasitics, and then find troublesome parasitic oscillations in production units. The reason for this is that the design has a parasitic tendency that remains below the verge of oscillation until some minor change in layout, circuitry, or tube parameters raises the gain of the parasitic circuit enough to start oscillation.

In most high frequency transmitters there are a great many resonances in the tank circuits at frequencies other than the desired operating frequency. Most of these parasitic resonant circuits are not coupled to the tube and have no significant tendency to oscillate. A few, however, are coupled to the tube in some form of oscillatory circuit. If the intra-stage isolation is not complete enough, oscillation at the parasitic frequency results. Those spurious circuits existing just below oscillation must be found and swamped to a safe level.

A method of accomplishing this is to feed a signal from a grid-dip oscillator into the grid of a stage and to observe the signal level in the plate circuit. The oscillator is tuned over the range of 50 to 200 mc. The test is made with all operating voltages applied to the stage, but with no fundamental excitation. The tuned

[*Continued on page 114*]

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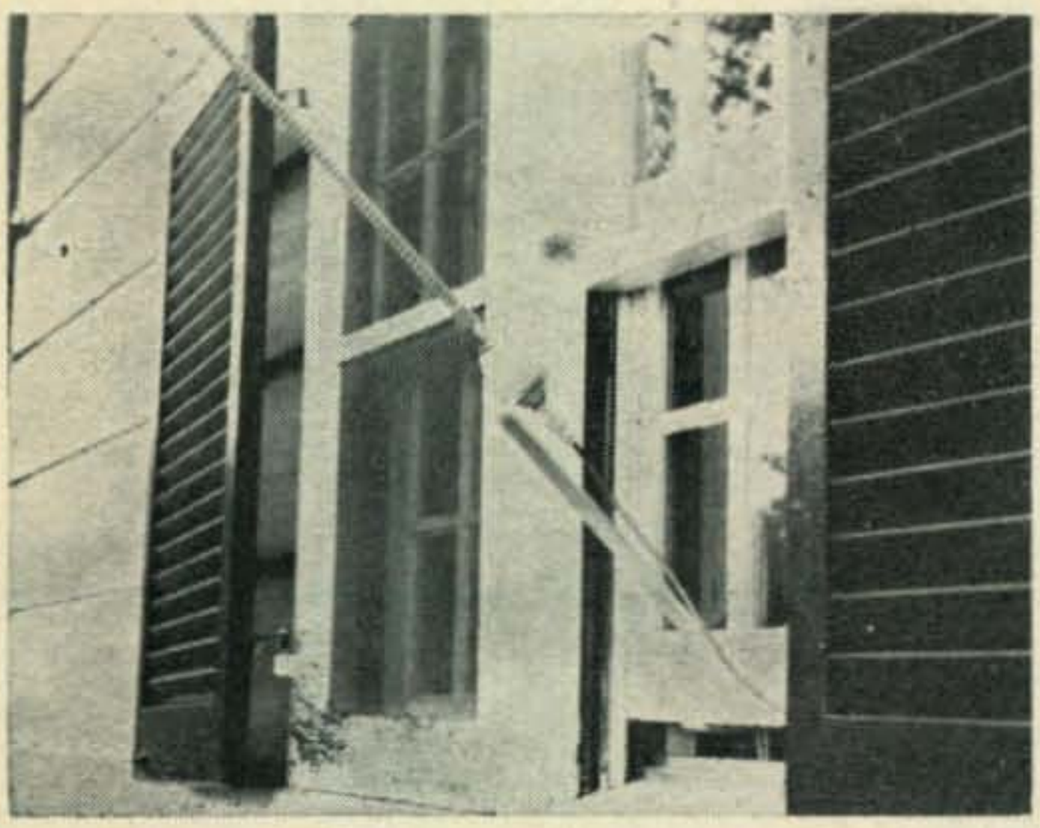

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WANTED: Model 19 metal teletype table, model 14 non-typing reperforator. Also TM 11-2201, 2210, 2236, 2238. Must be resonably priced. W4NZY, 119 North Birchwood Avenue, Louisville 6, Kentucky.

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Receiver AR-3, Q Multiplier, 80-40 meter transmitter, xtals, key $40. Misc. parts, must go, excellent. Gale O'Dell, Craigsville, W. Va.

Collins 75A-1, $215.00; 75-A-3, immaculate $315.00; Drake 1-A, $159.00; MM-2 scope, $89.00; Johnson KW Matchbox with bridge, $95.00. May trade. W8WGA.

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Transmitting Tubes [*from page 37*]

circuits of the stage are adjusted to the operating frequency. The "search" oscillator is tuned back and forth across the possible parasitic frequencies. When a parasitic frequency is hit, the plate current of the tube under test will change, and there may be a show of grid current. Each significant parasitic indication should be investigated. Circuit changes or suppression devices must then be added to reduce the parasitic response by 10 decibels or more in amplitude.

Happily, the radio amateur is not interested in production test methods such as this, but the procedure provides an idea of the technique necessary for complete parasitic control in mass production transmitting equipment. Time spent in examining your amplifier for possible parasitics, and the cure of these little devils, will pay big dividends in a clean-sounding, smoothly operating piece of equipment. ■